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MICROPEDOLOGY

by

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Micropedology treats of the investigation of soils by methods adapted to the use of small quantities of material and of the study and interpretation of details of soil morphology that are not visible to the unaided eye. Much can be seen and a different outlook on soil morphology and genesis can be obtained if the soil is studied under a dissecting or petrological microscope in the laboratory or field though the use of either out of doors is not very convenient.

The first book dealing solely with this subject was written in 1938 by W. L. Kubiena and in it the use of the microscope and microchemical methods in the study of soils is described and several examples are given of the kinds of observations made and how they are to be interpreted. This was followed ten years later by his "Entwicklungslehre des Bodens" in which the development of soils and development-sequences of soils are discussed, with particular reference to those on calcareous rocks. The importance of biological activity in soil formation is emphasised and micromorphological evidence is used in support of a genetic approach to the problems of soil development. In 1953 "The Soils of Europe" appeared in which Kubiena introduced a classification of soils giving great weight to soil genesis and making much use of micromorphological observations in recognizing and describing soil types.

Mick (1949) has remarked that "in the final analysis a study is only as good as the samples on which it is based", and in micropedological studies it is essential that the profiles investigated should be carefully chosen from sites whose history is known with some certainty and that samples taken should be good examples of the phenomena being studied. Samples of known orientation should be collected so that observations can be made on both vertical and transverse faces or sections (Kubiena, 1938). Coarse-structured soils can be sampled by carefully removing small blocks or entire peds[*] from the face and labelling them so that their orientation is known. Looser materials such as sandy or weakly structured soils and highly organic horizons are more conveniently collected in a sample frame (Kubiena, 1953) consisting of a shallow box, 3 x 2.5 x 1.5 in., with removable top and bottom; this can be eased into the soil with a stout knife and an undisturbed sample taken. A similar frame 1 x 1 x 1 in. has been found of more use in stony soils and has the additional advantage that, if necessary, the whole block can be removed and impregnated for sectioning.

Preparation of thin sections. During recent years attention has been focussed on the interpretation of thin sections although only a few pages of Kubiena's book (1938) are given to a description of their preparation. While of use in studies of organic and surface soils, there is a wealth of information to be obtained from sections of mineral soils and particularly of the subsurface layers. Several methods are available for the preparation of sections, but it is essential that all pore spaces should be completely filled with the impregnating medium so that the peds are firmly held in their relative positions during subsequent operations. Soils differ so much that probably no one medium is suitable for all. Natural waxes and mixtures of natural resins have been successfully used (Kubiena, 1938) but there are now available suitable transparent plastics having refractive indices near that of Canada balsam. In a recent paper by Dalrymple (1957) the names and addresses of suppliers of several suitable impregnating materials are given. While it is possible to impregnate a large porous ped, it may be necessary to use a small block or slice if the soil is dense and difficult to impregnate. After impregnation a thin slice is cut or sawn off and one side, ground flat and polished, is cemented to a flat microscope slide with Canada balsam, Kollolith or Lakeside 70. The excess thickness is removed by grinding with different grades of carborundum powder or other abrasive either dry or wetted with paraffin (kerosene) until the slice is thin enough. For most purposes a thickness of 30µ is adequate and may be checked by observing the polarization colours of suitable mineral grains, e.g. quartz or feldspar. Structures and some other features may sometimes be more readily recognized if a somewhat thicker slice is used. When finished the slide is thoroughly cleaned and a cover glass cemented on with cold Canada balsam or other cement.

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[*] A ped is an individual natural soil aggregate. (Soil Survey Manual, U.S.D.A.)

Polished impregnated blocks or thin sections can be used for estimating the volume percentage pore space by Rosiwall's method and for determining its variability (Swanson & Peterson, 1940). Portions can be removed from uncovered sections for microchemical investigation although little use has been made of this approach beyond ascertaining the chemical nature of efflorescences and concretions.

Stereoscopic microscope observations. The description and identification of the materials of superficial organic horizons are not easy in the field, but can be fairly readily done in the laboratory by dissecting a frame sample, when the essential similarities of the organic profile under different vegetation covers become apparent although their morphologies differ according to the flora and fauna present. During dissection some of the fauna can be captured for later identification and it is evident that the number and species of fauna profoundly affect the rate of destruction of plant remains and the kind of humus formed (Kuhnelt, 1950; Murphy, 1953). Useful classifications of soil fauna based on their action on plant remains have been made by Jacot (1940) and Fenton (1945).

The L-layer, of recently fallen plant remains, can be readily distinguished from earlier and partly destroyed fallings whose destruction by bacterial, fungal and faunal activity becomes obvious in the F-layer in which fungi can be recognized as well as the partly eaten plant remains and droppings of soil fauna that occur as black, round or cylindrical pellets of various sizes either loose, attached to or sometimes inside the remains. With increasing depth, droppings and their remains become more obvious at the expense of the plant remains which are eaten and reduced in size. The H-layer consists almost entirely of droppings, some mineral grains and a few resistant plant fragments. The droppings are recognizable in the upper part, but under weak pressure or through dispersion by percolating solutions their shape is lost and the base of the layer is amorphous, black and greasy. Thin sections of droppings show that they may contain a few very small fragments of undigested plant remains (plant splinters) and very small mineral grains.

By studying the micromorphology of organic horizons Kubiena (1953) has classified the humus forms and has described the main groups as dy, gyttja, sapropel and peat, formed under sub-aqueous conditions and raw-humus, moder and mull found under terrestrial conditions. There are several subtypes, each with a recognizable micromorphology, related more specifically to climate, vegetation and fauna. The identification and recognition of humus forms are of importance, for certain of them are associated with definite soil forms and are useful in classification. A detailed study of humus forms and their distribution in heath and woodland soils has been made by Jongerius (1956) who subdivides moder according to the fauna from which it originates, and finds a relation between the formation and mechanical transport of moder and of dispersed colloidal humus depending on the degree of podzolization. In poorer soils there is only infiltration of dispersed humus while more mechanical mixing occurs in the less podzolized soils.

Microscopic investigation with good field work assists in elucidating the genesis and course of development of soils such as the rendzina-like soils that have been carefully worked out by Kubiena (1948). These are developed on calcareous rocks and have A- and C-horizons only. In the early stages of development the A-horizon is a loose, rendzina-moder consisting of partly destroyed plant remains, numerous droppings from the drought-resistant fauna and mineral grains of calcite or dolomite. The droppings are well preserved and, as in all moders, mineral and organic matter can be mechanically separated. These primitive soils are shallow and support a scanty vegetation, but in the course of development a similar but deeper profile occurs under a grassy vegetation suitable for rough grazing. With increasing weathering, more clay is released, the soil becomes deeper and a more varied and moisture-loving fauna can exist. By passage through larger fauna, particularly earthworms, organic and mineral matter is inseparably mixed in the humus form of mull which is almost completely devoid of recognizable plant remains. Microscopic examination of such mull rendzinas shows the A-horizon to be composed almost entirely of worm-casts forming rounded aggregates. Such a soil is well aerated, for the stable crumb peds do not fit closely, but it also retains moisture adequate for crop growth.

A similar course of development of ranker-like soils can be traced on silicate rocks (Kubiena, 1953) but owing to the lack of calcium carbonate their subsequent development differs from that of the rendzina-like soils. Which stage of development of rendzina- or ranker-like soils is prominent in a landscape will depend, among other things, on such factors as the climate and nature of the rock.

Brown earths have a more complex profile of the type A (B)* C and in all sub-types except one (Alpine sod braunerde) the humus form is mull. Microscopic examination of peds of the (B)-horizon shows that they lack the smooth, rounded shapes of those in the A-horizon and are irregularly, often subangularly, shaped owing to shrinkage cracks developing. The soil is more or less spongy and the peds are porous or, in some cases when they are relatively dense, are fissured so that drainage is not impeded. These micromorphological features of the A- and (B)-horizons are indicative of good aeration and water retention; the production of mull denotes high biological activity, and organic matter is, therefore, quickly incorporated; furthermore, burrowing animals can penetrate the soil deeply and, by mixing it, some of the losses of nutrients by leaching are replaced. The soil is relatively stable and unlikely to suffer erosion or to develop an impermeable layer.

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* A (B)-horizon is one formed by deep-seated chemical weathering and simultaneous oxidation of the iron complexes; it is not an enriched horizon of illuviated substances (Kubiena, 1953).

The (B)-horizons of some soils derived directly from limestone have a quite different micromorphology from those described above and are found in several soil types, but it will be sufficient to describe some features of the terra fusca (Kubiena, 1953) developed on limestone in a humid climate. The humus form of the A-horizon is mull (or mull like moder) formed of worm-casts with a low humus content so that they are easily destroyed, and, on drying, the peds are somewhat angular. When examined microscopically the (B)-horizon looks waxy, very dense and non-porous, though fissured by shrinkage cracks, small ripple-like markings can often be seen on the ped surfaces, mineral grains appear to be embedded and when removed are clean and neither stained nor coated; the peds are angular or sub-angular and have sharp edges. Ferruginous or manganiferous concretions of various sizes have smooth surfaces and round shapes.

The micromorphology of this type of soil suggests that the surface would not retain its structure and under certain conditions it would not be easy to prepare a good seed-bed. The properties of the sub-soil indicate that natural drainage may also be somewhat impeded although water may pass along cracks and fissures between the peds.

Soil fabrics. One of the most important subjects of micromorphological investigations is the study and interpretation of the soil fabric, i.e., the arrangement of the components of the soil in relation to each other (Kubiena, 1938). The components of the fabric are mineral grains and the matrix, which is largely unresolvable and consists of clay minerals, finely divided sesquioxides and organic matter. The way in which the components are arranged determines the shapes and sizes of the cavities. From observations on soils from many parts of the world it appears that there may only be a few kinds of fabrics and attempts are being made to identify fabrics with specific soil types by attaching the soil name to the fabric, but, although a certain fabric may be associated with a particular soil, Kubiena (1938) has given examples of the same fabric occurring in different soils.

When seen in thin section the fabric of most brown earths is spongy with sinuous, rough-walled channels and holes. The mineral grains are in a brown-coloured matrix that is uniformly distributed and there are no areas of accumulation or concentration; iron or manganese concretions are also lacking. The clay matrix is granular and flocculated, though the degree of flocculation may be variable, and, when viewed between crossed polars, shows no birefringence phenomena. The properties of the fabric, particularly of the matrix, suggest that the constituents are immobile and that clay particles released or formed by weathering remain *in situ* in a flocculated state.

A very different picture is presented by the (B)-horizon of the terra fusca. The fabric is dense with very few cavities; channels and cracks are fairly straight and result from shrinkage. The mineral grains are embedded in a uniformly yellow-coloured matrix in which dark brown ferruginous concretions of circular cross-section and smooth outline often occur; similar manganiferous deposits are black. Viewed between crossed polars, brilliantly illuminated streaks displaying complete or partial (shadowy) extinction are strikingly visible along channels completely or partly filling holes and surrounding mineral grains, the appearance being caused by the regular arrangement of oriented clay particles.

The difference between these two fabrics is very striking and has been used by Kubiena (1948) as a broad distinction between 'erde' with a loose, porous fabric without obvious flow structures or doubly refractive streaks and 'lehm' having a dense, uniformly coloured, anisotropic matrix. The distinction originated from field observations of tropical soils, for those that are friable, loose, crumb-structured, stable and of low plasticity have an erde fabric (roterde, braunerde), while those that are easily dispersed and hence subject to erosion, and are plastic and form hard angular clods when dry, have a lehm fabric (rotlehm, braunlehm). In braunlehm and rotlehm, developed on siliceous rocks under tropical and subtropical conditions, the birefringent parts of the matrix do not exhibit marked common orientation, and the matrix is traversed by numerous, small, doubly refractive streaks. This matrix has been observed in a rotlehm from Cyprus (Osmond and Stephen, 1957).

Fabrics have been recorded by Peterson (1937), Frei and Cline (1949), McCaleb (1954) and Brewer (1956a), in which along channels and in cavities there is an accumulation of strongly oriented clay, which is often arranged in layers as shown by alternating lighter and darker coloured yellow or brown bands. Such a layered, strongly oriented accumulation of clay suggests clay migration in the profile and, indeed, it is difficult to think of any other mechanism by which it could have been produced.

Few micropedological investigations have yet been reported of the fabrics of lateritic soils, but there is little doubt of their complexity, for Humbert (1948), describing sections of laterites, writes of hydrous iron oxides orienting themselves around nuclei, losing water, reducing their surface and forming compact concretions; also of the growth of concretions and conducting veins to entangle crystalline constituents. More recently Alexander *et al* (1956) discussing the hardening of laterite point out that "pisoliths, concretions or definitely defined separate bodies are found in most laterites . . . there are bodies of different sorts where a particular kind of material or mineral mixture has separated." In laterites with saprolitic structures "a lattice-like network of oriented films of kaolin upon which is overlaid the impregnating iron mineral, usually goethite," is commonly found. According to Kubiena (1956b) laterization manifests itself in all kinds of pore spaces in the subsurface layers of soils with braunlehm or rotlehm characters. In addition to translucent areas, the fabric includes dense, opaque parts with a great variety of form—filaments, flakes, coatings, etc., and silica appears as opal, chalcedony and secondary quartz. He is thus able to distinguish between the effects of laterization and "rubefication" which refers to the tendency to the production of red colorations in tropical soils of braunlehm character. The fabric of rubified soils has little variety of form, is uniformly translucent, is fairly uniformly red in colour, and silica in the forms given above is absent. It appears that there is a development sequence from one fabric to another. Brewer (1957) gives a brief description of the sequence of fabrics from braunlehm to roterde via rubefied braunlehm, rotlehm and earthy rotlehm.

It is evident that the elucidation of the genesis of fabrics is of great interest and will throw light on many problems of soil formation.

Soil genesis and classification. Soil microscopy is being increasingly applied to problems of soil genesis, one of the commonest being to find reasons for the formation of B- or (B)-horizons. Microchemical studies and examination of thin sections of B-horizons of humus or iron podzols show that the grains are coated with iron-humus compounds of the same character as the matrix forming intergranular braces or cement between the grains and that their disposition is what would be expected if they were deposited from solution (Kubiena, 1938). After percolating aqueous leaf extracts through columns of quartz grains coated with ferric oxide, Bloomfield (1956a) found the appearance of the columns strongly reminiscent of a podzol profile and in all cases the "B-horizons" were 1-2 cm below the level to which the sand had dried out.

Thin sections of brown earths show clean grains in an immobile clay matrix and no evidence of illuviation of ferruginous compounds or clay. It can be assumed that oxidative weathering is responsible for the production of ferruginous coatings on clay minerals released or formed *in situ* and that podzolization does not occur because of the activity of the numerous mull-forming fauna whose activity in the surface does not allow a raw-humus to form which could provide the necessary reducing and solvent agents.

The B-horizon of grey-brown podzolic soils is characterized by an increased clay content compared with that of the A-horizon and also by the presence of clay skins. Frei and Cline (1949) described the micromorphology of a sequence of soils from grey-brown podzolic soils through intergrades to brown podzolic soils. From the non-uniform distribution of clay and its optically continuous orientation along channel walls they concluded it unlikely that the clay was residual but that its accumulation was due to percolating clay suspensions. Studies of the intergrade soils showed that as the A-horizons of the grey-brown podzolic soils became depleted of bases, a progressive degradation of the upper part of the B-horizon occurred and micromorphological features of the brown podzolic soils developed in the A-horizons. Furthermore, the mineral grains became coated similarly to those thicker coatings found in the B-horizons of podzols. A similar conclusion regarding the origin of some of the clay in the B-horizon of certain loess soils had been reached by Peterson (1937) who also noted the partly layered structure of such illuviated clay; the same phenomenon has been reported by McCaleb (1954) and Brewer (1956a).

Not every case of increased clay content in the B-horizon need be explained by clay illuviation, for Mick (1949), after calculating "weathering indices" from the ratios of certain resistant minerals to show the conformity of soil and parent material, concluded, from physical and mineralogical determinations, that the increase in clay content in the B-horizon is not necessarily caused by this process and that it is probably not so dominant in the formation of the grey-brown podzolic profile as ha been commonly supposed. This view has been substantiated by Brewer (1955) by a careful study by similar methods of a yellow podzolic soil. He found that the higher clay content of the B-horizon can be explained by weathering of minerals and synthesis of clay *in situ*. Thin sections were used to demonstrate this and to show that the micromorphology associated with clay movement was lacking

Raeside (1956), examining the micromorphology of a New Zealand yellow-grey earth with a hardpan and characteristic columnar structure, found the pores "lined with laminated birefringent colloid" and "all mineral grains coated with yellow-brown colloid which acts as a cementing agent." The amount of colloid, however, was insufficient to explain the physical character which apparently is attributed to close packing of the material. He considers the soil polygenetic and that "the maritime situation contributes soluble salts that promote clay shift in a manner analogous to that in solodized solonetz soils . . . .". In some solodized solonetz soils in Australia, however, Brewer (1956b) found that thick clay coatings, assumed to be due to illuviation from their position in the profile, were only weakly oriented and suggested that the clay suspension had been flocculated and the clay deposited without much orientation in a zone of high electrolyte content.

In an examination of two profiles developed on essentially the same parent material under different drainage conditions and classified as a red-brown earth and a grey and brown soil of heavy texture respectively, Brewer (1956a) found that in the free-draining red-brown earth, clay migration, for which good permeability is necessary, had played an important part in its development. Although migration had occurred in the upper part of the more poorly drained soil its role in soil formation was much smaller and in the impermeable B_{21}-horizon it only occurred where pore spaces were unusually large. The investigation also led to the conclusion that the soils differ genetically—the more poorly drained soil being polygenetic—and Brewer observes that although they had been originally separated on a morphological basis, the sections show that much greater differences exist and he remarks that evidence derived from sections should be considered in classification.

Further point is given to this comment in Brewer's report (1957) that Laruelle, working on some Belgian soils correlated with the grey-brown podzolic soils of the U.S.A., fails to find much strongly oriented clay coating in the B-horizon. Macromorphologically the soils are similar, but the microscope reveals an important difference which emphasises Raeside's plea (1956) for more care in correlating soils in widely separated geographical regions "unless it can be established that all morphological characteristics are identical and the environmental histories of the soils are similar." It is evident that the micromorphology should be considered in correlating and classifying soils. Kubiena (1956a) has suggested that in many cases the grey-brown podzolic soils of the U.S.A. are synonymous with the Central European lessivé soils, the B-horizons of which have a fabric resembling that in a braunerde with numerous, often broad, channels and cavity walls lined by optically oriented clay and generally so disposed as to suggest downward clay migration.

Experimental. It is not easy to verify experimentally some of the hypotheses put forward to interpret micromorphological observations and in many instances only the accumulation of evidence, supplemented by observations from other lines of work, may enable definite conclusions to be drawn.

The investigation of the production of humus forms by biological activity is not easy in view of the many species of both flora and fauna that take part. Murphy (1953) refers to several investigations of the palatibility of litter of various tree species, and also confirms that broadleaf species are more readily and quickly eaten by mites than are coniferous species. Kubiena (1948) demonstrated the formation in six months of an artificial protorendzina by allowing collembola (*Sinella coeca*) to feed on plant remains. By adding dolomitic marl to the protorendzina and allowing earthworms to work upon the mixture for a few months, it was converted to a mass resembling the surface soil of a mull rendzina.

Experiments demonstrating the orientation of clay have been carried out by Brewer (1956b) who showed that doubly refractive films can be formed by infiltrating dilute clay suspensions into columns of sand grains. The nature of the dominant exchangeable cation had no effect on the orientation of a clay consisting of 60 per cent illite, 40 per cent kaolinite and some quartz. Flocculated clay formed oriented clay films when mixed with sand and silt and allowed to dry with continual stirring, provided the sand/clay ratio was high, but less orientation occurred if the ratio was low or if a significant amount of silt was present.

While there seems little doubt that clay migrates through the soil profile the dynamics of the movement are not clear. In many publications Kubiena has pointed to the protective action of humus colloids in those situations where they can be found, and there are many cases where this explanation is feasible. Where humus colloids are absent or present in only small amount, he has postulated that colloidal silicic acid may act in the same way, as indicated by Reifenberg's experiments on the action of silica sols on solid ferric oxide. Bloomfield (1956b) has shown that aqueous leaf extracts are capable of deflocculating clay and hence that they may play a part in the mobilization of clay in the upper soil horizons.

Conclusion. In this short review of the kind of problems investigated by micropedological methods it is evident that the application of microscopic techniques has an important part to play in elucidating the dynamics of soil formation and of the processes that occur inside the soil body. After visiting many workers in soil microscopy, Brewer (1957) remarks that "foremost among the processes studied . . . are:—

(*a*) Biological activity, humification and development of humus forms.
(*b*) Illuviation of clay-size material, humus and sesquioxides.
(*c*) Reorganization of clay-size material by differential movement caused by wetting and drying, root pressure, etc.
(*d*) Separation and concentration of sesquioxides within soil horizons.
(*e*) Development of structure forms.
(*f*) Separation and crystallization of secondary silica.
(*g*) *In situ* weathering of some primary rock-forming minerals."

This list by no means exhausts the problems that await solution, for many more arise if the later development of the subject of palaeopedology is taken into account. Many papers of great interest have been written on this subject, some of which have been reviewed by Osmond (1956). Nothing has been said of the contribution of petrological studies to the weathering of rocks and minerals under different soil-forming conditions to give the constituents building the soil fabric, nor of the insight to be gained by the X-ray analysis of clay minerals and the determination of their shapes and sizes by electron microscopy. Soil is such a complex body that its problems will only be resolved by the combined efforts of workers in many branches of science.

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